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# Decimal Time

*Unlike the metric system of measurements, decimal time did not survive the French Revolution. But is dividing the day by tens a possibility for the future?*

> La Convention, pour rendre complet le système de numération décimale, a décrété, en conséquence, que le jour serait divisé en dix parties, chaque partie en dix autres, et ainsi de suite, jusqu'à la plus petite portion commensurable de la durée.
>
> —J. Guillaume (*1*)

These words, at the height of the French Revolution 185 years ago, highlight the decision of the revolutionary National Convention to adopt decimal time. For a tumultuous period of eighteen months, the new French Republic moved toward decimal time, along with the introduction of a decimal calendar and the metric system. Based on the principle of dividing the day by tens, one decimal day would consist of 10 decimal hours, each hour would consist of 100 decimal minutes, and each decimal minute, 100 decimal seconds.

A comparison of systems for weights and measures to systems for measuring time units uncovers a remarkable difference. Over the world, many different systems of weights and measures have competed one with another. For time, however, one system is almost completely dominant: the 24-hour day with 60-minute hours and a start time at midnight. Alternate time systems do exist, but they differ principally in the definition of the beginning of the day. For several Middle Eastern religions, dawn or evening marks the beginning of the day. For astronomical timekeeping, until 1925, the beginning of the day was marked at noon so that observation over a night could occur entirely in one "day." Astronomers make use of a slightly different time system to define celestial events—sidereal time, with the length of a sidereal day defined by the time interval between two successive passes of a star overhead. A completely decimal system is also used by astronomers—the Julian date (*2*), which counts days and decimal fractions of days from a time in 4713 B.C., with the day beginning at noon Greenwich Mean Time.

In the recent past, small but important changes in the definitions of our units of time have been instituted (*3*). These include the introduction of the cesium atomic beam standard, in the 1960s, to define the second and the introduction of the leap second, in 1972, to take care of small irregularities in the rotation of the earth. Changes, then, are possible in time systems. Decimal time, with a history of several hundred years, is an elegant and intriguing approach to marking time. Although the possibility of adopting decimal time has been discussed many times, the material is widely dispersed. My purpose in this article is to summarize some of this material as a coherent whole.

The 10-decimal-hour day is among several time systems that could be considered. One element that must be taken into account in devising any new system is what units are best preserved. For instance, is it most important to preserve, or nearly preserve, the second, the minute, the hour, or the day? A system that comes close to preserving the hour is one which divides the day into 20 hours, the so-called vigesimal system. Another scheme, suggested 80 years ago by Rey-Pailhade (*4*), certainly the most prolific writer on decimal time, divides the day into 100 parts, each called *cé*, for "centiday," but this approach employs a unit that is quite far out of character with the hour. Another quasidecimal system, attributed to Sarrauton, defines the hour as the fundamental unit and divides it into 100 decimal minutes (*5*). This system of decimal fractions of hours is now used for some applications, including time and motion studies. Conventional clocks with 100-division scales are available on special order for this purpose (*6*).

The sexagesimal number system for timekeeping does not use the same arithmetic mode as most of our other calculations. This factor alone is a complication in a world populated by decimal calculators, human or otherwise, but the problem is more extensive than that. The time system now in use is not just a sexagesimal system but a mixed decimal-sexagesimal system. The problem is brought home if the number of milliseconds in a period of several days has to be calculated. Time units smaller than seconds are divided into decimal units—nanoseconds, microseconds, and milliseconds. For time intervals between a second and a day, a quasi-sexagesimal system, in which hours are counted by 24 rather than by 60 is

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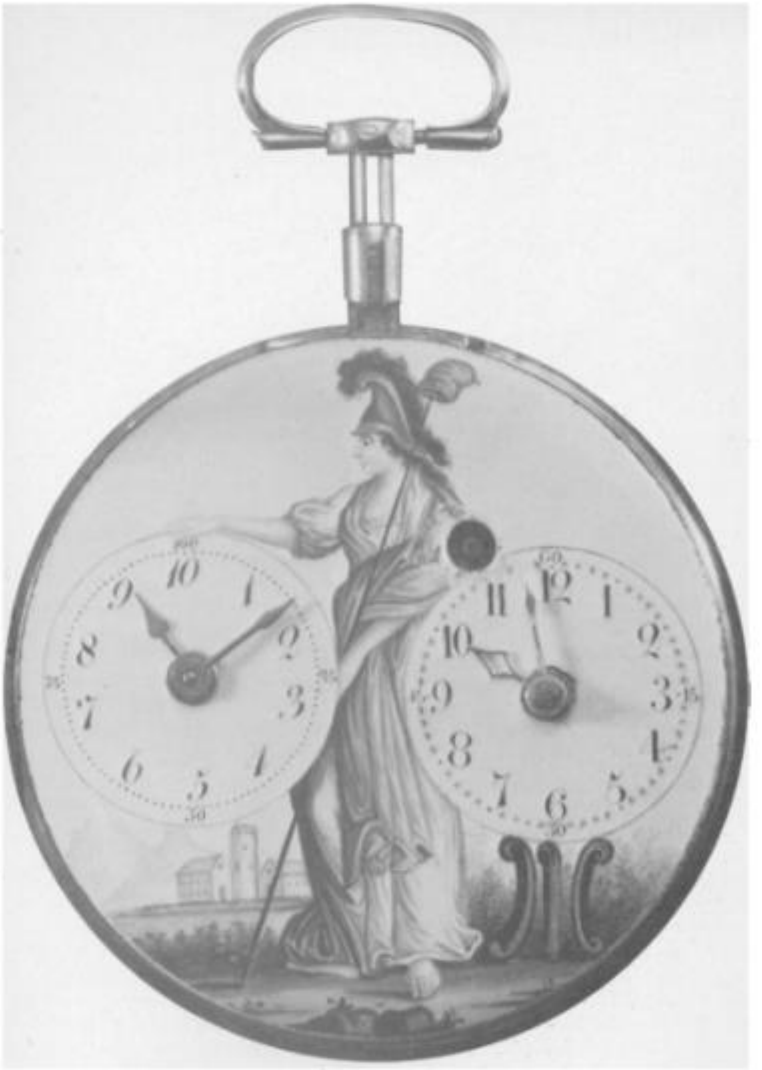


Figure 1. On this exquisite example of a double-dial watch from the French Revolution, Liberté, or La France, turns her back on the conventional dial and looks expectantly toward the dial representing the new decimal timekeeping system. Double-dial watches have a decimal dial synchronized with a conventional dial on the same frame. (From the Collection of Au Vieux Cadran, Paris. Reprinted from ref. *43*.)

used. This situation complicates calculations involving the addition of time intervals to arrive at an absolute time, such as occur in navigation problems. As another example, trying to find the difference in times before and after noon is complicated—and makes the learning of time particularly difficult for children. With decimal time, this problem is essentially nonexistent.

In discussing decimal time, it is important to use names for the units that are convenient and manifestly take account of the decimal nature of the system. At the same time, the names should not give rise to confusion. In this article, the unit of time obtained by dividing the day into 10 parts will be called a decimal hour; divisions of the decimal hour into 100 parts will be called decimal minutes; and divisions of the decimal minute into 100 parts will be referred to as decimal seconds. I do not propose or recommend these designations as the best names, and will discuss some other possibilities below.

## Early history

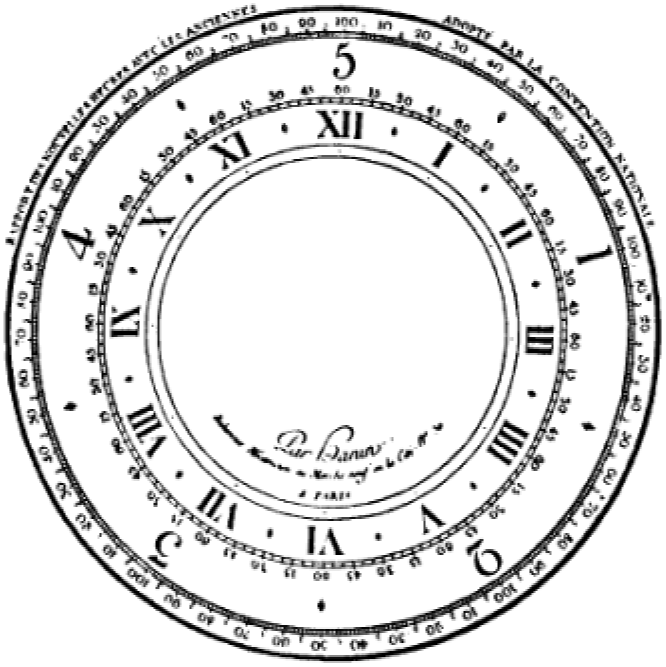
The history of decimal time is imbedded in the general history of time. The division of the day into 24 hours is attributed to the Egyptians, while the use of 60 minutes and 60 seconds probably has its root in the Babylonian sexagesimal number system (*7*). A virtue often attributed to this system is that 12 and 60 have more common factors than the numbers in the decimal system so that simple division is facilitated.

In all likelihood, early commerce in the Mediterranean required rather accurate weights and measures, whereas no such need existed for time, since communication was by slow-moving ocean vessels or caravans. And yet early Mediterranean civilizations must have had some sense of very small time intervals and how to measure them; Hipparchus, around 140 B.C., lists many stars scattered at intervals of right ascension, with their right ascension separated so as to mark intervals of one sidereal hour (*8*). This concordance is accurate to about one minute of time.

In the early Middle Ages, the day was separated into two 12-"hour" periods, with each period coinciding with daylight or darkness, so that the length of the "hours" for day and night were different and changed from day to day (*9*). These intervals were designated as *tides*. This form still remains in English in the words *eventide* and *noontide*. Although this system works reasonably well in the Mediterranean, where the day does not change drastically with the seasons of the year, it is not satisfactory at northern latitudes, where the changes can be large over the course of six months. The Orient adopted a 12-hour day, with variable day and night hours, but this was displaced by the occidental system during the upsurge of Western commerce with the Orient in the nineteenth century (*10*).

The first practical use of small time units came with the introduction of clocks around the fourteenth century. The second hand made its appearance on clocks about A.D. 1400. *Secundus* in Latin means "following";

Figure 2. This concordance of decimal time, prepared during the French Revolution by Hanin, appears in the records of the Revolutionary Committee of Public Instruction. Decimal hours are in Arabic, while conventional hours are given by Roman numerals. This type of concordance was sometimes appended to a watch or clock face to convert it to a quasidecimal instrument.



literally, it could be viewed as a second-minute—that is, a second small division of time. The fact that the clock preceded to some extent the need for standards of communication at small time intervals may have led to the universality of the present time system.

In 1670, Gabriel Mouton, the Vicar of St. Paul in Lyons, laid the foundation for the decimal metric system. By 1754, d'Alembert, writing in the *Encyclopédie* on the decimal system, was advocating decimal coinage, decimal weights and measures—and decimal time (*11*). In 1788, *L'Almanach des Honnêtes Gens* pointed out the possibility of decimal time (*12*), and at nearly the same time a parliamentary lawyer published a monograph suggesting complete decimalization including time (*13*).

## The French "revolution"

It was on this foundation, the rationale of a coordinated system of decimal weights and measures, that Talleyrand (*14*) in 1790 called on the Estates-Général, the first legislative body of the French Revolution, to adopt the metric system. Real legislative work on the new system awaited the start of the French Republic and the convening of the National Convention on 22 September 1792, the beginning of year "one" for the revolutionary calendar. A commission of weights and measures was appointed, and later the Convention established a commission from within the Committee of Public Instruction to look into reform of the calendar.

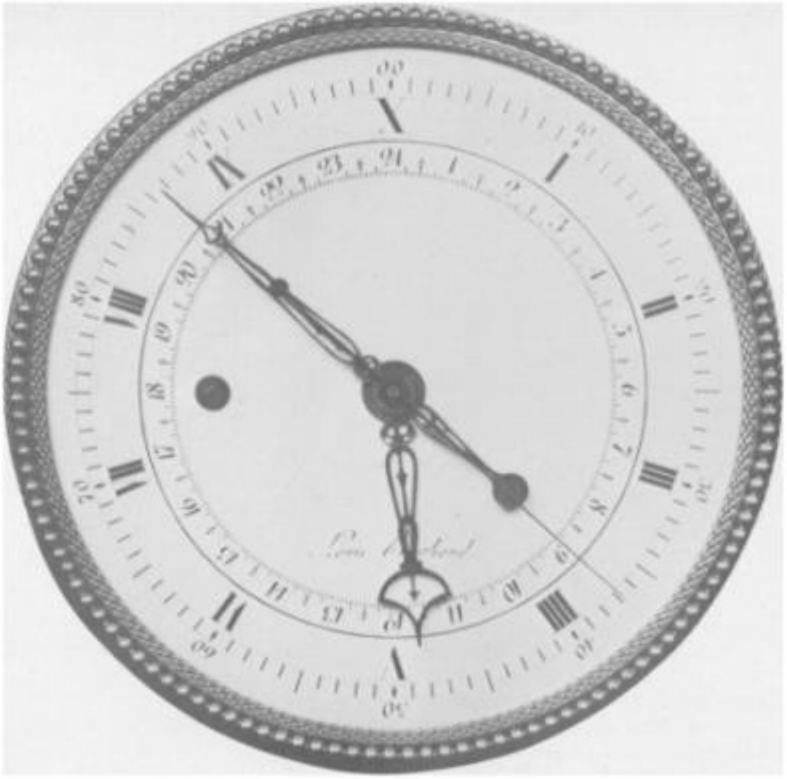
Gilbert Romme, a forty-two-year-old delegate to the Convention with a bent for physics and mathematics, spearheaded the development of the calendar and a decimal time system, relying for technical advice on a blue-ribbon scientific panel. The gentlemen of the Committee of Public Instruction were well aware of the historical foundations of time measurements; one report maps a broad history of time in a few short paragraphs that touch on nearly every significant aspect of a system of time units (*1*). By September 1793, well into the Reign of Terror, Romme was reporting back to the Convention on decimal time.

In October 1793, only a month after Marie Antoinette lost her head, the new republican calendar was adopted, along with a provision to adopt decimal time on 22 September 1794. The Convention had certain reservations concerning Romme's choice for names for the new calendar, and a special commission was appointed including Romme to review the names. In six days they returned with the names for the months—reflecting the Northern Hemisphere seasons—that are so much a part of revolutionary history. The full cycle of thirty-day months in the revolutionary calendar began on 22 September with the month of Vendémiaire, followed by Brumaire, Frimaire, Nivôse, Pluviôse, Ventôse, Germinal, Floréal, Prairial, Messidor, Thermidor, and Fructidor. The remaining five days of the year (six in leap year) were designated as Sans-Culottides. The entire package was knitted into one decree in November 1793.

The calendar system with a 10-day week, called a *décade*, may have been devised, at least in part, to break down the influence of the Catholic Church in France by eliminating the Christian system of holy days and the regular adherence to Saints' Days. Friguglietti, in his comprehensive study of the revolutionary calendar (*15*), has pointed out that it did not have the effect anticipated: the French peasants adopted the 10-day week with a holiday every tenth day, but continued to celebrate the Christian calendar as well, leading to even more holidays. To gain acceptance for the new state and the calendar, Robespierre had instituted the Festival of the Supreme Being, but not too many *décades* passed before Robespierre went to the same fate as Marie Antoinette. The total use of the calendar lasted ten to twelve years. Decimal time fared even worse and was formally disposed of after less than two years of tentative use.

Romme was among those who were appointed to devise a contest for the design of a decimal clock. Several days after the decree adopting the calendar, the Convention received a decimal watch, and by February 1794 plans for the decimal clock competition had been laid out. It is clear from Lagrange's testimony to the Committee of Public Instruction (*16*) that this competition was intended to go

Figure 3. This decimal clock, which still keeps time, was designed and constructed during the French Revolution by Louis Berthoud, whose father, Ferdinand, served on the jury to select timepieces in the Revolution. The short hour hand does double duty by also giving conventional time. The clock, now in operation at the Conservatoire des Arts et Métiers, Paris, includes a decimal-second hand.



far beyond the mere design of a clock. Rather, it was intended to pinpoint the very design of the time system. New major divisions, such as 100 rather than something closer to 24 or 10, could be entertained. The entries for the contest were to be in by 19 June 1794, a rather odd date that makes more sense when interpreted in terms of the revolutionary calendar—1 Messidor.

In the summer of 1794, a jury of distinguished scientists and horologers was set up to decide the questions relating to decimal time. The jury deliberated through the fall and completed its work by December, but the original date for the general adoption of decimal time had come and gone without the system's going into force. In the spring of 1795, the whole question of measurement units was brought to a head. Prieur of Côte d'Or, a military engineer highly placed in the Revolution and an associate of Romme's, presented the general case for the adoption of a metric system of weights and measures to the Convention, but he did not press for the adoption of a decimal time system. The Convention approved the metric system of weights and measures while suspending the adoption of decimal time indefinitely (*17*). It should be noted that Prieur did not foreclose completely the use of decimal time. He suggested that it might be convenient for navigation, trigonometry, astronomy, and some experimental applications and then might slowly come into more general use as its advantages became established.

There are a few more sporadic references to decimal time in the revolutionary period. Some committee reports may not have been published until 1796 (*18*). A 1797 marriage certificate for Elisa Bonaparte cites the marriage time as 7 hours, 5 *décimes* (6:00 P.M.), indicating that divisions by tenths of a decimal hour were being used (*19*). Marseille, the place where her marriage was recorded, used decimal time for official recordings until 1800, and an English diplomat saw a decimal clock at Tuileries as late as November 1801 (*20*). On the other hand, no move to decimal time seems to have accompanied the second wave of enforcement of the revolutionary calendar in 1797. Perhaps this can be understood by realizing that the second introduction of the calendar was again an antichurch device while the rational question of decimal time and the metric system had already been decided.

There is a tragic footnote to the story of decimal time in the Revolution. Only a month and a half after the Convention suspended decimal time, Romme was swept up in political events. He was arrested, tried for treason, and condemned to death in one of the last agonies of the Revolution. On hearing the sentence he committed suicide by stabbing himself. (Advocates of new time systems must perforce be sobered by Romme's fate.) On the other hand, Prieur was able to survive this period and live to a ripe old age, albeit out of power. Perhaps Prieur's expediency in backing the metric system of weights and measures while giving up on decimal time is an example of a compromiser and survivor at work.

One of the central questions about decimal time is why the system failed so totally in the French Revolution. Rey-Pailhade suggested several reasons (*4*): (1) decimal calculations were little understood at the time of the introduction of the new system; (2) serious modifications would have been required on existing timekeeping devices; (3) new terms would have had to be introduced for the new units. Friguglietti (*15*) cites Prieur as giving five official reasons for suspending the adoption of decimal time when the metric system was sanctioned in 1795: (1) it would offer no marked advantage over the old system and would "throw disfavor" over the new system of measures as well; (2) the strength of habit would make enforcement impossible, if indeed such regulations were lawful; (3) popular confusion would result; (4) the expense of changing all timepieces would be enormous; and (5) citizens would intensely dislike converting their watches to the new system, and watchmakers would be unable to dispose of their old stock. Frigulietti himself suggests that the reason was political rather than practical: "The decision of the Convention to abandon decimalized time reflects the growing reaction that followed the disintegration of the revolutionary government."

Several open questions remain concerning the situation in the French Revolution. How fast was decimal time introduced and how rapidly did it fade? How widespread was the use of decimal time? What was the public reaction to the new system during its quasiformal use? Rey-Pailhade (*21*) has shed some light on these questions in several historical studies focusing on Toulouse, a strongly Jacobin city. He found that within weeks after the decrees in 1793, some use was being made of the new dates and time units. By 1794, a truly decimal clock was functioning on the town hall and apparently continued in sporadic operation for several years—even after the suspension of decimal time. Decimal times were often used to record official activities.

## After the Revolution

The developments in time specification since the French Revolution have been less dramatic than those considered during the Revolution. Perhaps the foremost was the introduction of the concept of standard time, which can be directly traced to the evolution of the large railroad network in the United States. Each community had maintained its own basic zero hour, but, as railroad systems grew, the time in a major city was used to set the time for an entire area. For compact countries such as France, the time in use in the principal city could serve for the entire country. In the United States, the size of the nation required a standard system, and time zones were adopted around 1880 (*22*) and eventually spread around the entire globe.

Another significant time standard was introduced when alternating electrical current came into use. In Europe, this cycle divides the second into 50 units, while in the United States a 60-cycle standard is used. I wonder if, at least in part, the choice was not predicated on adhering to the sexagesimal system. The present one-sixtieth of a second division constitutes a difficult overlay on the easier division into milliseconds in electronic applications.

Since the Revolution, there has been only sporadic interest in decimal time. In 1856, Richard Dover Statter (*23*), a Liverpool watchmaker, wrote a pamphlet on the advantages of this system; he appears to have been unaware of its use during the French Revolution. The Library of Congress has on file a pamphlet from 1886 protesting the possible introduction of decimal time, by Richard Goodridge, of Manitoba, Canada (*24*). (I have not been able to determine the source of his concern.)

Rey-Pailhade mounted a concerted drive advocating decimal time in France, which continued from 1890 to well into the twentieth century. He notes that in February 1899 a proposal was introduced into the French Chamber of Deputies to re-adopt decimal time (*20*); obviously nothing came of it. Rey-Pailhade had a fine sense of how to stimulate public awareness to the possibilities of decimal time. For example, he arranged yacht races using decimal time, with decimal timepieces as prizes (*25*). In 1917, he offered a prize of 1,000 francs to the Société Amicale des Ingénieurs de Saint-Étienne for efforts in utilizing decimal time in industry (*26*). His own notes show no evidence that the prize was claimed.

## Decimal time conventions

The definitions of the units of time as we know them today are essentially fixed by the rotation of the earth; decimal time could also be defined on this basis. Are other standards for time units possible? Using the lifetime or frequency of some natural process is one possibility (*27*). The actual standard for the second is now defined on the basis of the cesium atomic beam standard to avoid problems associated with variations in the rotation rate of the earth. In practical terms, however, the earth's rotation has a transcending effect on our daily lives. The day may come when time will have to be defined for colonies on the moon or on other planets. Unless necessitated by biological rhythms tuned to the earth's system, extraterrestrial habitats may adopt their own definition of a day as the local timekeeping standard. This practice has been followed, in part, on the Viking probes to Mars, where the length of the day is slightly different.

Consider the present practice of using A.M. and P.M. This division of the day does not have much practical value and has already been discontinued where 24-hour clocks are used. The practice of dividing the day into two parts is related to another question: Is a 20-hour day or a 10-hour day a more satisfactory approach to decimal time? A 20-hour day might be justified if the day were considered to be split naturally into two parts, such as "night" and "day" or the equivalent of A.M. and P.M. A 20-hour day has the advantage that the newly defined hour would be more closely akin to the present hour. However, introducing 20 into the system gives rise to mixed units.

An alternate approach is to divide the day into 100 rather than 10 basic units. Rey-Pailhade sketched a possible clock face for this system (*4*); however, amusingly, he fell into the trap of dividing his unit for one-hundredth of a day, the *cé*, into four parts rather than five or ten. A difficulty with using 100 units is that the principal time unit may be too short, about fifteen of our present minutes. Mettler (*28*) suggests that this unit would lead to impractical watches. Nevertheless, he does make the point that it may be important to consider a unit intermediate between the decimal minute and decimal hour that divides the day into a hundred parts. He calls this interval a *scheduling unit*, noting that it can form a convenient division for many of the shorter human activities, such as short meals or class breaks.

In establishing decimal time conventions, new names must be found for the new units. During the French Revolution, the forms *minute décimale* and *seconde décimale* were used. These forms, with the obvious possibility of being abbreviated to the first words, which are terms already in use, could easily lead to confusion between the old and the new time systems. Mettler has given a nice summary of a number of candidate names for time units (*28*). He elected *chrona* for the decimal hour; derived from the Greek for time, the word was, he argued, reasonably translingual. For the scheduling unit, he used the obvious choice, *decichrona*; for decimal minutes, *centichrona*; and for decimal seconds, *rema*, from the Russian word for time. In some cases, the names suggested by Mettler are longish words. It would seem preferable to introduce short, translingual words that relate to time words in present languages. Possibilities might be *watch* for decimal hour, *min* for decimal minute, and *sec* for decimal second. Clearly, the choice of names could have a profound impact on the acceptance of a new time system.

The choice for a zero hour in the day is also important in establishing a time system. In our existing time system, midnight and midday have the advantage that they are easily defined. A zero time somewhere around 3:00 A.M. is convenient because the changeover from one day to the next interferes least with daily activities. Our present nomenclature for time suffers from a serious inconsistency: the half-hour point between midnight and 1:00 A.M. is identified as 12:30, in effect associating that hour with the wrong day. In a decimal system, this time might be identified with zero and possibly called null-fifty, rather than ten-fifty. Midnight was used as the zero hour for the decimal time system in the French Revolution.

## Decimal clocks and watches

Examples of the many decimal clocks and watches made during the French Revolution can be found in publications and in a number of collections of historical clocks. The proceedings of the French Revolutionary Committee of Public Instruction contain an excellent 12-hour/5-decimal-hour dial designed by Hanin that offers a concordance for decimal time (see Fig. 2) (*29*). Several additional Hanin dials (*30*) are shown in standard books on French clocks.

The type of concordance shown in Figure 2 served as the simplest adaptation to decimal time. It was added to a watch or clock face, to make it a quasidecimal instrument. Gélis (*31*) offers an illustration of just such a watch by Ferdinand Berthoud, one of the greatest French horologers, with a picture of Le Pelletier, a revolutionary hero, on the obverse side. The Seth Atwood collection, in Rockford, Illinois, contains an interesting ormolu and marble clock with a decimal dial inside the normal 12-hour circle. The style appears to be pre-revolutionary Louis XVI. The decimal hours are marked in Roman numerals, somewhat out of keeping with a rational decimal system. Interestingly, the markings of the decimal dial are irregular—dividing the decimal-hour interval into eight parts rather than ten. It is almost as though the clock had been modified after construction to have a decimal dial. Another apparently modified dial is even stranger: a watch signed "de la Combe," at the Conservatoire des Arts et Métiers, has the 12-hour circle divided into 10 decimal hours rather than 5, leading, in effect, to a 20-hour day.

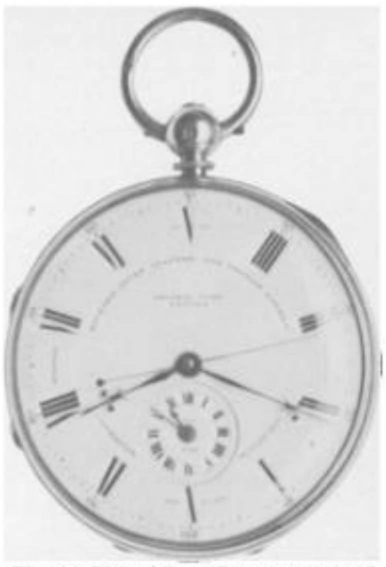


Figure 4. Richard Dover Statter constructed this decimal watch around 1860. The decimal time reading no longer coincides with the dial face, probably because the hands were improperly positioned during a cleaning. Note the counterclockwise dial, the use of Roman numerals, and the placing of midnight at the bottom of the dial. (From the collection of the Worshipful Company of Clockmakers, London.)

The scheme of adding only a dial loses the timekeeping precision of a minute or decimal-minute hand. Many true decimal timepieces incorporated both decimal-minute and decimal-hour hands. One lovely watch has a decimal and a conventional dial side by side: Liberté, or La France, holding a staff capped by a revolutionary cockade, stands facing the decimal dial, seeming to hold it with an obvious preference (Fig. 1). The hands on the two dials are synchronized to give equivalent time indications. A number of other revolutionary decimal watches with dual dials were built on the same main frame, sometimes with auxiliary dials to indicate 30-day months. I have seen photographs of at least six of these, and no two have had the same dial-face illustration. The works of one of these early decimal watches with dual dials has been described recently (*32*; see also ref. *33*): the main gear train, which is a conventional watch, is coupled by a decimal idler to the decimal dial, and the watch uses a conventional verge escapement and fusee drive.

Other revolutionary clocks and watches made no concession to the old time, opting wholly for a purely decimal face. Figure 3 illustrates a clock of this type that is still in operation, complete with a decimal second hand. On more than 80 percent of the dial faces I have seen, Arabic numbers were used rather than Roman numerals, in distinct contrast to Louis XVI timepieces made before the Revolution and somewhat more pronounced than the use of Arabic numerals in Directoire and Empire pieces after the Revolution.

It would be interesting to see if any of the decimal clocks showed evidence of metric conversion. This could be done by comparing gear diameters to those in pieces by the same makers several years earlier. Case diameters for some revolutionary watches appear to be distinctly larger than late Louis XVI watches. Some of the decimal clocks were chiming. The French horologer Robert Robin built a clock with several bells, one to strike decimal hours and one to strike every 10 decimal minutes (*34*).

Examples of revolutionary decimal watches and clocks are not common. Revolutionary calendar clocks seem to be more frequent. Of course, the period the revolutionary calendar was in effect was substantially longer, but a second factor may be the matter of style. The clockmakers do not seem to have obtained any fixed expression, possibly because of serious revolutionary disturbances in the clockmaking trade. Clock cases range from rococo to simple boxes. Perhaps collectors have been more interested in the beautiful Louis XVI and the dramatic Directoire and Empire pieces.

I have seen photographs of approximately fifteen watches and ten clocks purported to be from the French Revolution; 75 percent are fully decimal—that is, they have a special gear train to produce the decimal time indication. I have found no way to estimate how many decimal timepieces were produced during the Revolution. Figures in Baillie, a classic book on the history of clocks (*34*), suggest that France imported 120,000 watches annually at the time of the Revolution. Most timepieces made during the Revolution were not decimal. Based on these figures, the number of decimal timepieces constructed might have been anywhere between 100 and 10,000.

Since the Revolution a smattering of decimal timepieces have been constructed. In 1862, Statter, the Liverpool watchmaker and pamphleteer, built a decimal watch (*35*), now in the collection of the Worshipful Company of Clockmakers in London (Fig. 4). Statter adopted the convention of placing ten at the bottom of the dial and using a counterclockwise rotation. His dial uses Roman numerals, a throwback that the French revolutionaries would probably not have countenanced. Statter may have also had a chiming clock constructed, set to chime every 25 decimal minutes (*35*). The Seth Atwood collection includes a large astronomical clock built between 1865 and 1895. One dial, labeled *Zukünftige Zeit*, or future time, is set for a 20-hour day. Roman numerals are used to mark the dial.

It seems clear that Rey-Pailhade had some decimal watches constructed by M. L. LeRoy on a commercial basis (*36*). Prices are variously quoted as 50 (*37*) and 150 francs (*38*). One marvelous example includes a decimal dial, a 40-hour-day dial, and a normal dial incorporating decimal minutes following the system of Sarrauton. Paul Ditischeim also produced several decimal watches around 1900 (*39*).

To study the impact of decimal time, it is fruitful to employ decimal clocks in real timekeeping situations. For this purpose, I have built several electronic digital decimal clocks and have had one electromechanical clock constructed. (Building a mechanical clock is beyond the range of most people and many machine shops; modification of an existing clock gear train usually is not practical.) Ordinary mechanical clocks with circular faces have an advantage over digital clocks in that they are manifestly decimal, with numbers running from zero through nine, or one through ten, rather than one through twelve.

There are several alternative approaches to constructing an electronic decimal clock. One possibility is to use a crystal oscillator electronically cut to give a frequency that can be readily divided into decimal seconds. Another is to use the 50- or 60-cycle alternating line voltage to generate a time signal and to operate on that signal to generate the decimal units. Mettler (*28*) has noted that it is easy to build a digital decimal clock that shows decimal hours and decimal minutes in this way. This can be done by dividing the 60-hertz line frequency by 5,184 and feeding the resulting signal into a three-digit decimal scaler. For a 50-Hz line frequency, the magic number is 4,320. I have available a circuit diagram for constructing a digital decimal clock incorporating decimal seconds.

Still another alternative is to use some sort of computing device to convert conventional time to decimal time periodically, say, once every second. This can be done by using a microprocessor or a programmable electronic calculator and has the advantage that the clock can be set using conventional time. I have such a program suitable for use with a Texas Instrument Programmable Calculator.

Mechanical clocks can be constructed in several ways. One possibility, sometimes used in the French Revolution, is to make a 5-hour clock face on a regular clock. If only the hour hand is used, a clock of this sort gives correct, if not precise, time indications. The problem is that the second and minute hands are meaningless. Constructing a decimal-time face brings home an interesting ramification of the decimal system vis-à-vis the sexagesimal system: dividing a circle by 50 using the normal 360° divisions. This problem highlights the possible interest in a decimal degree system. One satisfactory approach I have used is to enlarge the Hanin concordance photographically.

Edward Cielaszyk, of Westclox, in La Salle, Illinois, has devised a gear train for converting a standard 60-Hz clock motor, normally operating at 900 revolutions per minute, to a decimal device. This modern decimal clock is shown in Figure 5.

Some commentators on decimal time, such as Statter, have dealt with the question of clockwise-versus-counterclockwise motion for mechanical clocks. Although the counterclockwise motion would automatically define a decimal clock, the matter seems to be of little practical relevance to the definition of time units.

## Impacts of decimal time

To assay the advantages and problems of decimal time, I have operated decimal clocks in a number of situations—offices where the clocks were exposed to scientific, clerical, and administrative personnel; an operation ready-room administering tightly coordinated scientific programs; at home; and a junior high school classroom. All impressions were drawn subjectively. There seemed to be no preference for 20-hour days rather than 10-hour days, even though the hour in the first case is closer to the conventional hour. Some objected that the use of 20 hours continued an existing problem. Few people commented on starting the day at times other than midnight—perhaps because they were already so confused by the new units that other alterations were only minor perturbations.

One of the most difficult problems in adapting to decimal time is overcoming the use of sixty for time intervals: electronics experts well acclimated to electronic scalers that count by tens had no trouble grasping the principle of the decimal time system; however, when the seconds' scalers on a digital decimal clock reached 59 and then went on to count 60 and 61, their immediate reaction was that the electronics had failed. Quoting half and quarter hours results in the same ingrained confusion. For the time halfway between 7 and 8, "7:30" spontaneously pops out rather than the proper "7:50." With an adult, these re-educational prob-

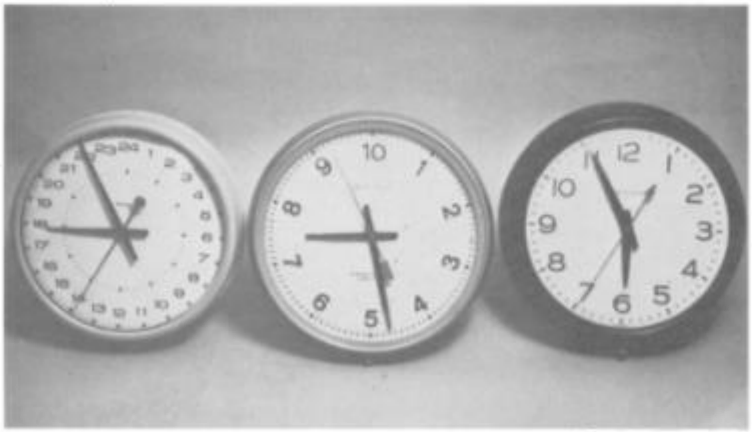


Figure 5. A contemporary decimal clock constructed by Edward Cielaszyk, of Westclox, is flanked on either side by more conventional timepieces. All three have been synchronized. It is amusing that during operating tests with the decimal clock the tilted numbers caused nearly as much comment as the decimal scale did.

lems last for months, at least. However, in a one-month trial in a classroom with no other clock, the students quickly learned the decimal time for the end of class.

One of the principal questions related to the length of the hour concerns the length of the work day. With decimal time the day is not readily divisible into the usual three, roughly equal parts—work, leisure, and sleep. Also, division of a 24-hour day into three shifts is a convenient disposition of work in a round-the-clock operation. Although division into four intervals may be something that the future holds, it is not widely used at present. Nor should segmentation of the work day be dictated by the nature of the time units. I regard the fact that the day cannot be easily divided into three parts as one of the more serious problems related to the general use of decimal time. One possible solution would be to run shifts on something like a 3-decimal-hour, 4-decimal-hour, 3-decimal-hour basis, with the 4-decimal hour shift during daylight. Part of the problem could be ameliorated by using units of one-tenth the decimal hour, about 15 minutes, as suggested by Rey-Pailhade and Mettler.

From a psychological standpoint, the length of seconds and minutes seems to be less important. The decimal second, in particular, is close enough in length to the conventional second that the change is nearly indiscernible for most people.

Changing the length of the second would have an extensive impact on the present metric system of units (see ref. *40*). Although individual changes would not be drastic, many quantities—such as velocity, acceleration, energy, pressure, power, and electric current—would be changed. Time appears only to the first or second power in most physical quantities, and thus the general change would be either 15 or 30 percent, which is probably sufficient to eliminate misidentification of new and old units, but not so drastic as to make it difficult to acclimate to the new units. Rao has prepared an extensive summary of the values of the revised metric units employing decimal time (*41*).

Adopting decimal time would make it necessary to widen the time zones. For a day consisting of 10 decimal hours, the world would most naturally be divided into only 10 time zones. The time of sunrise and sunset would differ drastically across such broad zones, but no easy way to circumvent this problem is apparent. Use of 20 time zones, subdivided by halves of decimal hours, would introduce clocks staggered by 50 decimal minutes, which could lead to great confusion. On the other hand, a smaller number of time zones could be advantageous. The four time zones of the United States, for example, already cause some complications in television programming. Introducing only two time zones might bring more coherence into transcontinental communication. A related problem associated with the longer decimal hour would be a more significant shift from Daylight Time to Standard Time. If this were done by a full decimal hour, the change would be equivalent to about two and a half hours. On the other hand, with wider time zones, a summer-winter shift might not be desirable anyway.

One way to circumvent both these problems would be to redefine the time of activities in different parts of a time zone. Canonical times for certain activities would be different in different parts of a single zone. As an illustration, lunch might normally occur at noon, or 5:00 in decimal time, in one part of the zone and half an hour after noon, or about 5:20 decimal, in another part of the zone. A similar approach is already used in some parts of the country to spread out traffic loads in cities by alternating starting times for different businesses. Bartlett (*27*) has suggested that the introduction of a single world time—the equivalent of Greenwich Mean Time—would be useful in any case. People living in different places would just acclimate their times for activities to a one-world standard of time.

The introduction of decimal time would result in real costs for clock conversion, but unlike the metrification of weights and measures, only the tools of measuring time would have to be changed. Clock conversion is a thin cost that would be widely shared and easily borne, unlike the situation in the French Revolution, when clocks were relatively more expensive.

It has already been noted that the dominant time system is rather free of competing units. Wide use of decimal time would result in a transition period when both units were in use. Metrification advocates sometimes argue that the problems with our foot-pound system is not its nondecimal character but the fact that it is not a universal system. However, decimalization alone has, in many cases, been a sufficient reason to change units. An excellent recent example is the decimalization of the British currency.

How could a shift to decimal time be implemented? The French Revolution offers some excellent paths to avoid. (In fact, a better understanding of the failure of decimal time in the French Revolution might help to avoid some pitfalls in the present metrification program in the United States.) Increasing use within the sciences, following the lines suggested by Prieur, could eventually lead to wider overall use. Perhaps an approach could be followed similar to that now being used in the United States to introduce Celsius temperatures, in which both units are quoted together. In 1856, Statter (*23*) suggested that decimal time first be used for railroad schedules. This could now be broadened to include all communication and transportation arrangements.

Wide use of decimal time would bring a number of simplifications into our measurements of time. While problems exist—principally with the lengthening of the hour and its impact on the division of the day and time zones, a transition period with two sets of time units, and an inability to divide the day into three parts—there appear to be ways to work around them. Changing the units of time would represent a modification of our daily life as drastic as the introduction of the metric system in the United States or decimal coinage in England. Whether general acceptance could be found for such a program is a real question. I believe that the possibilities merit some discussion.

Prieur's words that closed the door on decimal time's only practical trial, but still left a tiny crack open, are as logical today as they were in 1795 (*42*):

> On sait que dans plusieurs objets du service de la marine, dans les calculs astronomiques ou trigonométriques, et pour des expériences délicates, la division décimale du temps est plus commode. Il sera donc bon de la réserver pour ces cas, en attendant que l'usage puisse s'en répandre plus généralement, ce qui ce fera de soi-même insensiblement.

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